

Cooperative Robot Movements for Guiding and Regrouping People using Cost Function Evaluation

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Abstract—The objective of this research is to optimize robots’ cooperative work and obtain the minimum displacement of humans in a guiding people mission, where some individuals can escape from the formation and must be regrouped by robots. The guiding mission is done in an urban environment, with obstacles and building constraints, where people can move freely and using multiple mobile robots which work cooperatively. In this paper, the forces that actuate toward robots will be studied, which are the forces between robots and humans and the forces between humans. Our goal is to find out the minimum work required for robots to lead and regroup people. We have developed a cost function that minimizes the work required in order to do this cooperative task.

I. INTRODUCTION

The interaction between social robotics and cooperative robotics areas is a new field of study. Therefore, the number of publications that exist nowadays is quiet short, specifically, if we refer to the study of guiding a group of people in urban areas with several robots. We can find some works using a single robot leading people in exhibitions and museums [2], or in hospitals [3]. In previous work [4], a model for guiding people in a dynamic environment using several robots working in a cooperative way was presented. This model is called “Discrete Time Motion” (DTM), which is used to represent people and robot motions.

In this research we present a method to optimize locally the tasks assignment to robots for doing their missions. Robots’ assignation are done by analyzing the minimum work required to do such task, where the function to minimize is based on one hand, by robot’s motion, and, on the other hand, by the impact of such motions on people’s displacement.

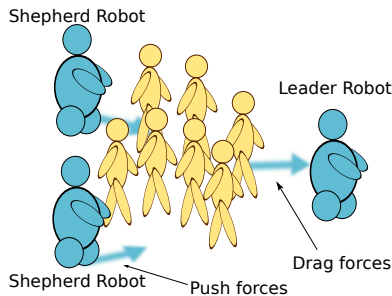


Fig. 1. Guiding people using a group of cooperative robots. Representation of the forces acting on people coming from robots: push and drag forces applied by Shepherd and Leader robots, respectively.

II. OPTIMAL ROBOT TASK ASSIGNMENT FOR COOPERATIVE MISSION

The cost function, described below, speaks in Work terms, and it can be divided as: (i) Robot work motion, and (ii) Human work motion.

In order to know what robots’ tasks are, we have considered the following situations: (i) The leader robot has to guide people, (ii) one robot has to look for the person (or people) that can potentially escape from the crowd formation and push him (or them) to regroup him (or them) into group, and, (iii) one robot has to go behind the people in order to push them in case that the crowd formation is broken down.

The Robot tasks that we are considering are, *Leader task* which computes a path planning and moves to the next point, where exists a *drag force* that will attract people behind the robot. *Looking for a person that goes away task*: The robot moves to the estimated position of the individual who goes away from the crowd formation, the estimation is computed using a Particle Filter [1]. *Pushing task*: The robot pushes a person that has gone away in order to reach the crowd formation. *Crowd traversing task*: The robot has to move through the formation to achieve the estimated position of the person that goes away from the crowd formation. In this work we are not taken into account this situation, due to safety reasons. We use the equations defined in previous works on human behavior with other individuals [6]. Working with autonomous mobile robots, the robot i work motion is expressed by:

$$f_i^m = m_i a_i \quad (1)$$

$$W_i^m = f_i^m \Delta s_i \quad (2)$$

where m_i is the mass of the i -th robot, a_i its acceleration and Δs_i the space traversed by the robot to achieve its goal.

The effect of robots on people as forces is: *leader robot*: attractive (dragging) force, it is inversely proportional to the distance, until a certain distance, and, *shepherding robot*: Repulsive (pushing, traversing) force, has a repulsive effect inside people’s living space.

The dragging force is necessary when the leader robot guides the group of people from one place to another. It acts as an attractive force, the force applied by robot leader i to each person j and the dragging work are defined by:

$$f_{ij}^d(t) = -C_{ij}\vec{n}_{ij}(t) = -C_{ij}\frac{x_i(t) - x_j(t)}{d_{ij}(t)} \quad (3)$$

$$d_{ij}(t) = \|x_i(t) - x_j(t)\| \quad (4)$$

$$W_d = \sum f_{ij}^d \Delta s_j, \forall \text{ person } j \quad (5)$$

where $d_{ij}(t)$ is the normalized vector pointing from person j to robot i at instant t . See [5] for more information about the parameter C_{ij} , which reflects the attraction coefficient over the individual j , and it depends on the distance between the robot leader and person j . Where Δs_j is the distance traveled by the person j .

The *Pushing force* is given by the repulsive effect developed by shepherding robot on the group of people, for regrouping a person (or the broken crowd) in the main crowd formation. The territorial effect may be described as a repulsive social force, and the work can be computed as:

$$f_{ij}^p = A_i \exp^{(r_{ij} - d_{ij})/B_i} \vec{n}_{ij} \left(\lambda_i + (1 + \lambda_i) \frac{1 + \cos(\phi_{ij})}{2} \right) \quad (6)$$

$$W_p = \sum f_{ij}^p(t) \Delta s_j, \forall \text{ person in } \Omega_i \quad (7)$$

Where A_i is the interaction strength, $r_{ij} = r_i + r_j$ the sum of the radii of robot i and person j , usually people has radii of one meter, and robots 1.5 m, B_i parameter of repulsive interaction, $d_{ij}(t) = \|x_i(t) - x_j(t)\|$ is the distance of the mass center of robot i and person j . Finally, with the choice $\lambda < 1$, the parameter reflects the situation in front of a pedestrian has a larger impact on his behavior than things happening behind. The angle $\phi_{ij}(t)$ denotes the angle between the direction $\vec{e}_i(t)$ of motion and the direction $-\vec{n}_{ij}(t)$ of the object exerting the repulsive force. See [5]. Where Ω_i is the set of people in which one of the helper robots have reached the living space.

And last but not least, the *Traversing force* is determined by the forces applied by the robot when is traversing the crowd. As we have said before, in this research we considered this force infinity. The cost function for robot i , given a specific task, is the following one:

$$W_i = \delta_m W_i^m + \delta_d W_i^d + \delta_p W_i^p + \delta_t W_i^t \quad (8)$$

Where k could be *pushing*, *dragging*, *traversing* or *motion* and δ_k is 1 if this task k is assigned, and 0 if this task is not assigned. Finally, the task assignment for the robots will be the one which locally minimizes the minimum assigned work cost, which is the one required to do the global task. It is computed by the following way:

$$C = \operatorname{argmin}\{W_{total}(c)\}, \forall \text{ configuration } c \quad (9)$$

where the *Configurations* mean how the tasks are distributed among the robots, for each configuration c robots compute W_{total} which is the addition of all W_i for all robots i that are working cooperatively.

III. EXPERIMENTS AND RESULTS

The results we will expose correspond to a synthetic experiment. We have considered one scenarios that robots can find in the North Campus of UPC, with open areas and cross areas. In this experiment, the dynamical models of the persons, we

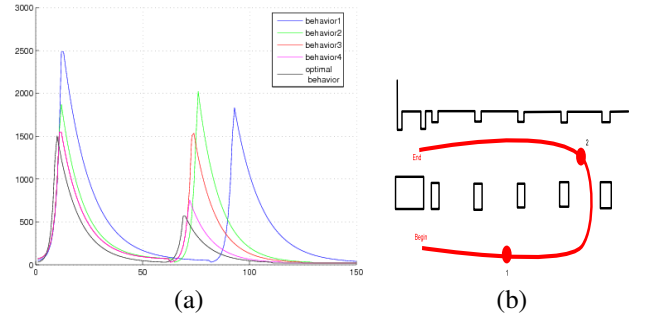


Fig. 2. (a) Evolution of the cost function along time of different behaviors of robots when people are escaping in two different instants of time. In (b) the path followed by the group is shown. Behavior 1: Robot Leader looks for people who are escaping. Behavior 2: Shepherd Robots look for people who are escaping without choosing the shortest way. Behavior 3: Shepherd Robots interchange their positions before looking for people who are escaping. Behavior 4: Shepherd robot which is nearest of people who are escaping is the responsible for resolving this mission without considering the forces presented before. Behavior 5: Robots choose the configuration which minimizes the cost function. (b) Trajectory followed by a group of people being guided by three robots, the computation of the cost function is shown. Point 1 and 2 are the representation where people have tried to escape.

have considered a group of 9 persons, will follow the models described by Helbing et al. [6].

In Fig. 2(a) we present the evolution of the cost function computed using different robots behaviors, it can be seen that the behavior that obtains the lower cost is the one which follows the optimization of the cost function presented previously. In Fig. 2(b) the trajectory the group has followed is presented. Hence, the cost function minimizes globally the work of the group of robots along all the mission.

IV. CONCLUSIONS

We have presented a new cost function for optimizing cooperative robot movements for guiding and regrouping people in a guiding missions. In contrast to existing approaches, our method can tackle more realistic situations, such as dealing with large environments with obstacles, or regrouping people who left the group. For that reason, this work can be applied in some real robots applications, for instance, guiding people in emergency areas, or acting as a robot companion. In future work, we are going to study the relation between the number of robots required and the number of people who are guided.

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